Original Research Article

Parametric Evaluation of Biogas Production from Saw Dust andTreated Human Faeces: Optimal (Custom) Design Approach

Abstract

As energy demand is increasing astronomically, fossil-based fuels became scarce and more expensive, and carbon dioxide emission levels became of greater concern. Thus, this research aim to bioconvertsthe co-digestion of sawdust and treated human faeces to produce biogas, a carbon-neutral gas to replace fossil fuels. From the outcome, the logistic function model performance was satisfactory in the simulation of the experimental process. The codigestion of sawdust and human faeces at 2.5 kg each produced the highest biogas output of 5.43 L using Optimal (Custom) Design of Mixture approach. The high coefficient of determination (R^2) ranging between 0.9959 - 0.9879 and standard deviation of 0.023 - 0.321 for temperature - biogas yield respectively, fall within an ideal range. Thus, the model proved to be a useful tool in predicting anaerobic digestion and biogas production processes. Furthermore, the FTIR analysis of sawdust and human faeces indicates their potential to produce biogas if subjected to anaerobic environment. In addition, the GCMS analyzed the % of methane to be 62.76% which is within accepted range. Thus, this experiment can be translated to an industrial scale biogas production for cooking and electricity to boost local economy and alleviate poverty.

Keyword: Biogas, Optimal (Custom) Design of Mixture, Human faeces, Sawdust, Characterization

Introduction

Environmental pollution by solid wastes disposals and lack of access to adequate energy resourcesare among the major challenges facing the human populace globally [1, 2, 3, 4, 5]. As energy demand is increasing astronomically, fossil-based fuels became scarce, more expensive, and carbon dioxide emission levels became of greater concern [2]. Therefore, the need to search forsubstitute like renewable energy sources from locally available and assesible resources in the quest forhuman survival and national development globally [2, 6, 7]. Sustainableenergy resources comprises hydro, solar, wind, biomass, etc. [3, 6, 8]. Biodiesel, bioethanol and biogas can be generated from biomass origin, but the ease of producing biogas is easier compared to other types of biomass origin [1].Furthermore, the associated harmful environmental and social effects with the use of typical biomass and fossil fuel have heightened the upward interest in the search for green sources of energy globally [9, 10].

The advances of renewable energy such as biofuel is alleged to offer developing countries like Nigeria some panorama of self-reliant energy supplies at both the national and local levels, reducing their over reliance on fuels from fossil origin [1]. Biogas regarded as the methane-rich gas withits left-over regarded as biofertilizer are produced via an anaerobic digestion that breaks down the organic material inthe absence of air [11]. Anaerobic digesters help to convert the energy stored in organic materials present in manure into biogas via the various processes like hydrolyzes, acidogenesis, acetogenesis and methanogenesis[2, 12], with methanogenesis bacterials being the chief converter to CH_4 and CO_2 under anaerobic fermentation [12]. However, this gas are used as a fuel for cooking, lighting, and generating electricity [11, 13]. Cooking is the most convenient use ofbiogas [6, 14]. A biogas burner that burns with blue flame without odor is available in a wide-ranging capacity from 8ft to 100ft biogas consumption per hour. The biogas lamp consumes 2-3 ft per hour having an illumination capacity equivalent to 40W electric bulbs at 220-volt [11]. Biogas also can be fed directly into a gas-fired combustion turbine.This combustion then converts the energy stored in the bonds of the molecules of the methane confined in thebiogas into mechanical energy as its rotates a turbine. The mechanical energy produced by biogas combustion in anengine spins a turbine that produces electricity[11], opening up the vincinity for industraliazation thereby, creating jobs for the unemployed.

Biogas a colorless and combustible gas is produced via anaerobic fermentation of animal, plant, human, industrial, and municipal waste to produce methane (50-70%), Carbon dioxide (20-40%), and traces of other gases such as nitrogen, hydrogen, ammonia, hydrogen sulphide, water vapor, etc. [1, 2, 14, 15,16].

However, the composition of the mixture depends on the source of biological waste and the management of the digestion process [2]. Biogas is considered as a potential waste-to-energy technology that greatly contributesto reducing environmental pollution and most importantly in reducing the greenhouse gases effect caused by the indiscriminate waste disposal [2, 6, 17].

In Nigeria, research into biogas technology and its practical application are ongoing, though, has not received the deserved attention. Lack of adequate funding from the government and sponsorship by individuals or corporate bodies has hindered the advancement of this technology in Nigeria [1]. In addition to identification of economically feasible biomatetrialsand utilizing the right influencing elements from existing elements like temperature, mixing ratio, pH, retention duration, volatile solid (VS), carbon/nitrogen (C/N) ratio, total solids (TS) etc. Already biomaterials like water hyacinth, animal dung, cassava leaves,rice husk, corn cob, corn chaff, human faeces, sawdust etc.,have been documented as biogas production biomaterials[1, 2, 17], but no publication has reported the co-digestion of sawdust with human faeces let alone using optimal (custom) design,a subset of Mixture from Design Expert in addition to utilizing three outputs (temperature, pH and biogas output). Thus, the need for investigation in order to accelerate the rate of producing biogas.

Sawdust like any other biomaterials can be explored as a biogas source by applying current waste to energy techniques [13]. Sawdust as depicted in Fig. 1,is a small chips of wood referred to astheleft-over or waste biomass generated from woodworking operations like sawing, milling etc. [13].Additionally, utilization of raw material such as human waste (human faeces) is considered beneficial in terms of the process because it does not require additional starters (microorganisms seed), and a supply of microorganisms occurs endlessly during the feeding of raw materials[11, 17]. Therefore, there, is a need for Parametric Evaluation Of Biogas Production From Saw Dust and Treated Human Faeces using Optimal(Custom) Design approachto produce energy for electricity to address power shortages and compare with works already published with a view of converting waste to wealth.

Fig. 1: Sawdust from plank (wood)

2.0 Materials and Methods

2.1 Material

Fresh human faeces used in the study was collected from sewage disposal of septic tankers in Awka Anambra state while the sawdust was obtained from Timber market Awka, Anambra State of Nigeria. Distilled water, Buckner flask (1000 mL), conical flasks (500 ml), mercury in glass thermometer, digital pH meter), distilled water, delivery tubes, corks, measuring cylinder (200 mL), muffle furnace, Oven, connecting tubes, mortar and pestle and weighing balance, micro Kjeldahl, test-tubes; crucible; Buchner funnel. And all reagents used were of analytical standard.

2.2 Method

2.2.1 Pre-Treatment of Substrates

Human faeces were sun-dried for three days to remove moisture from them and thereafter oven-dried at 110˚C for 8 hours. It was then ground and sieved into small particle size < 2 μm. The sawdust was pretreated using the method described by [18].

Exactly 3.75kg of sawdust contained in a plastic water bath was soaked with 1.45N NH_4OH solution (1:1 ratio w/v) for 72 hours. Thereafter, the sawdust was thoroughly washed with distilled water and then dried in an oven at 80^{o}C for 72 hours. The dried pre-treated sawdust was then mixed thoroughly with an appropriate quantity of human faeces and 5 liters of running water before charging into the digester.

2.2.2 Characterization of Substrates

2.2.2.1 Determination of Ash Content

The residue remaining after the destruction of the organic matter of feeding stuff is referred to as ash. This was determined by the Method of [19].The silica dish was heated at 600^{o}C for 30 minutes and was cooled in a desiccator and weighed. Five (5g) of the sample was added inside the silica dish and the weight of the weighed silica dish + sample was taken. The silica dish containing the sample was then put into a heater in a fume cupboard to burn off the less volatile organic material. Pre-ashing was stopped when smoking stopped. The silica dish (crucible) was thereafter transferred into a cool muffled furnace and the temperature was increased to 600^{o}C and maintained until a whitish-grey as remains was obtained. The silica dish was then removed and cooled in a desiccator. The weight of the silica dish + ash was weighed and was noted. The % ash content was obtained as depicted in Enq (1).

$$\text{Ash} = \frac{\text{weight of silica dish} + \text{weight of ash} - \text{weight of silica dish}}{\text{Weight of sample}} \times 100 \qquad \text{Eqn (1)}$$

2.2.2.2 Determination of Moisture Content

A clean silica dish was ignited and cooled in a desiccator and the weight was taken. Exactly 2g of the sample was placed in the silica dish and the weight of the silica dish + sample was taken. The silica dish was then dried in the oven at 100^{o}C for 24 hours to constant weight (by reweighing after every 4 hours than after 30 minutes until a constant weight was obtained). The weight was taken and the % moisture content calculated as depicted in Eqn (2).

$$\text{moisture content} = \frac{\text{weight of sample} - \text{weight of silica dish} + \text{sample after drying}}{\text{Weight of sample taken}} \times 100 \qquad \text{Eqn (2)}$$

2.2.2.3 Determination of Volatile Solid (VS)

5 g of the samples were weighed initially in Petri dishes and placed in a muffle furnace at 500˚C for 4 hours. The samples were allowed to cool down in a desiccator and re-weighed again. The loss weight is now the volatile matter present in the samples using Eqn (3).

$$\text{VS} = \frac{\text{initial weight of sample} - \text{final weight after heating extraction } y}{Weight\ of\ sample\ taken} \times 100 \qquad \text{Eqn (3)}$$

2.2.2.4 Elemental composition

Mineral element analysis was determined according to the official method of the Association of Official Analytical Chemists [12]. One gram (1.0 gm) of each sample was added to 20 ml HNO_3 in a 100 ml beaker. The mixture was placed on a hot plate and the temperature was maintained at 130^{o}C for four hours until the solution became clear. After cooling, the solution was filtered through Whatman No.1 filter paper to remove the insoluble particles and made up to a final volume of 50 ml with distilled water in a standard flask. Suitable dilutions were made for each sample before analysis during this process. Potassium and sodium were determined using Jenway Digital Flame Photometer while other mineral elements were determined using Buck Scientific Atomic Absorption Spectrophotometer. The resulting solutions were analyzed using the levels of the metals extrapolated from the calibration graphs generated using standard metal solutions. The procedures employed in these determinations were as contained in themanufacturer's manual for the equipment.

2.2.2.5 FTIR Spectroscopy

The structural organization of the substrates was investigated to identify the functional group's presence. The adsorbents were examined using SHIMADZU FTIR-8400S spectrophotometer with the range 500 - 4000 cm^{-1}.

2.2.3 Experimental design

Seven batch Digesters (labeled 1-7) of 10-liters capacity were set up and were charged up to ¾ of the Digester volume, varying the number of human faeces and sawdust while the volume of water (5 L)added remained constant with three response (output) for 44 days (6 weeks). The experiment was modelled via optimization using optimal (Custom) Design of Mixture of Design Expert version 13, as despicted in Table 1 and Table 2. Sellecting: Point Exchange, Optimality; I, Editing model; quadratic and scheffe, Lack-of-fit points; 2 and Replicate points ; 2

Table1: Input Elements of Optimal (Custom) Design of Mixture

	Name	Units	Low	High
A [Mixture]	Human Faeces	Kg	0	5
B [Mixture]	Sawdust	Kg	0	5

Table 2: Output (Response) Element of Optimal (Custom) Design

	Name	Units
	Temperature	C
	pH	
	Biogas Yield	L

3. **Results and Discussion**

3.1 Characterization of feedstock

The characteristics of the substrate (sawdust) and inoculum (human faeces) are summarized in Table 3. The results of proximate analysis of human faeces and sawdust showed that sawdust contained less moisture, ash, fiber, C/N, and fat while there was a slight increase in protein, total solids, carbon, and volatile solids when compared with the sawdust. The human faece contained higher moisture content due to the nature of the waste.

Table 3: Proximate Analysis of the human faeces and sawdust.

PARAMETERS	HUMAN FAECES	SAWDUST
Moisture (%)	**83.55**	**27.23**
Ash (%)	**2.7**	**1.95**
Fibre (%)	**0.04**	**4.84**
Crude nitrogen (%)	**0.25**	**0.38**
Crude protein (%)	**1.62**	**2.34**
Fat content (%)	**0.15**	**5.23**
Total solids (%)	**15.32**	**72.65**
Carbon content (%)	**97.3**	**31.91**
Volatile solids (%)	**12.68**	**70.70**
Carbohydrate (%)	**15.32**	**58.30**

3.2 Fourier Transform Infrared (FTIR) Analysis of substrates

3.2.1 FTIR of Human Faeces

The FTIR spectra of human faeces as shown in Fig. 2, confirmed that the highest peak with frequency 1870.32 cm−1 suggests the presence of carbonyl compound as the main functional group in the human faeces sample. Also, the broadband with frequency (3421.6.402 - 3590 cm−1) exhibited RO-H (Alcohol) while the broadband (2900 – 270 cm^{-1}) exhibited aldehyde. The broadband frequency of (1670 - 1615 cm^{-1}) shows that C=C stretch is present. At broadband of (1600 - 1590 cm^{-1}), C=C stretch was revealed. A broadband (810 - 760 cm^{-1}) C-H bend was observed.

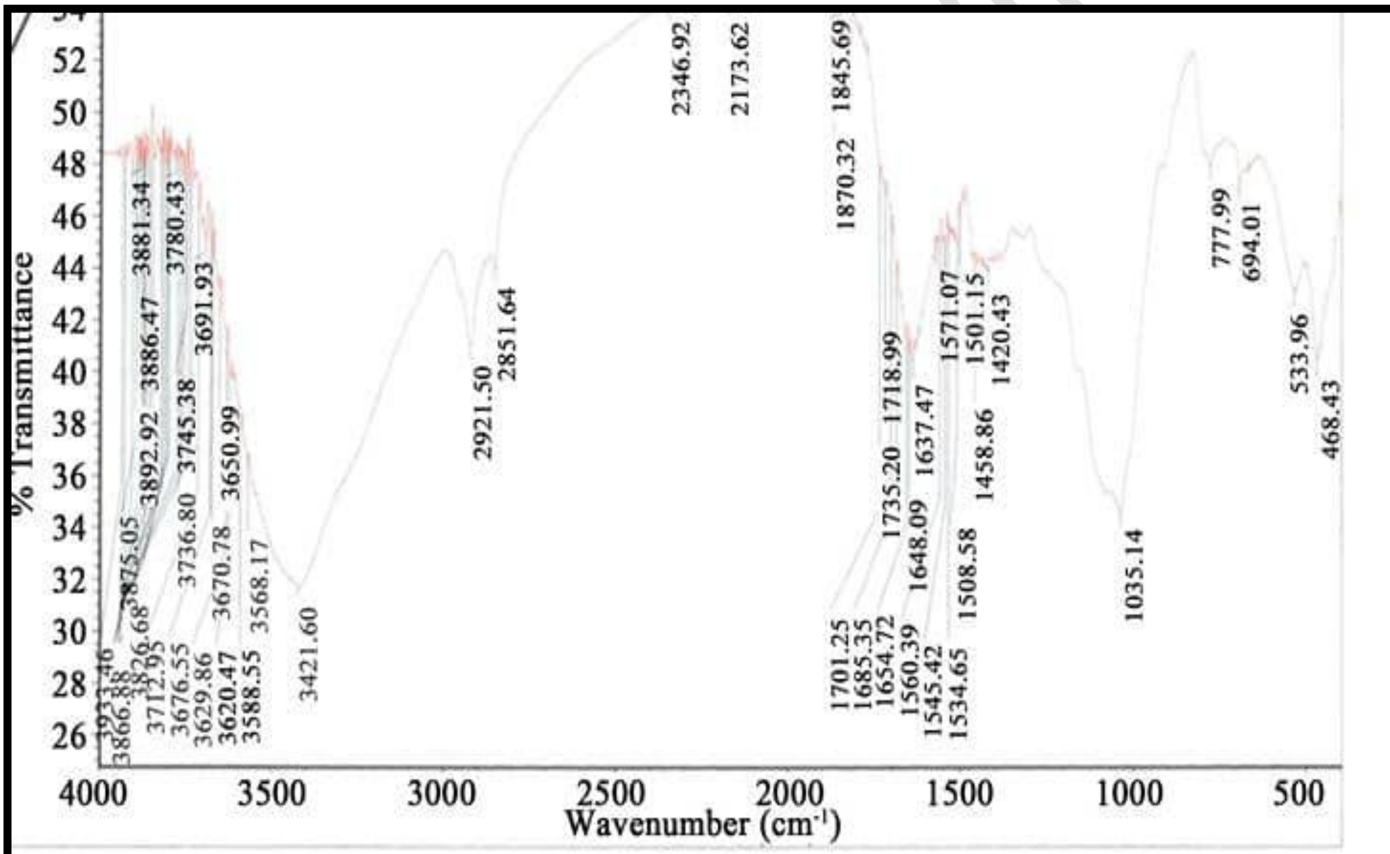


Fig. 2: FTIR spectra of human faeces

3.2.2 FTIR of Sawdust

The FTIR spectra of sawdust as shown in Fig. 3 suggest that the highest intensity (peak) with frequency 2149.60 cm−1 confirmed that C=C, short and narrow is the main functional group in the hardwood sawdust. The OH (secondary Alcohol) stretch broadband was shown with frequency (3626.52 cm−1) while 3391.07 cm−1 indicates normal polymeric “O-H” stretch. None bounded hydroxyl group O-H stretch, primary alcohol was shown in broadband 3646.03 cm−1. C-H, SP3 band was exhibited between (2852.95 - 2922.82 cm−1) while C=O huge band was shown at broadband (1651.55 cm−1 and 1732.37 cm−1).

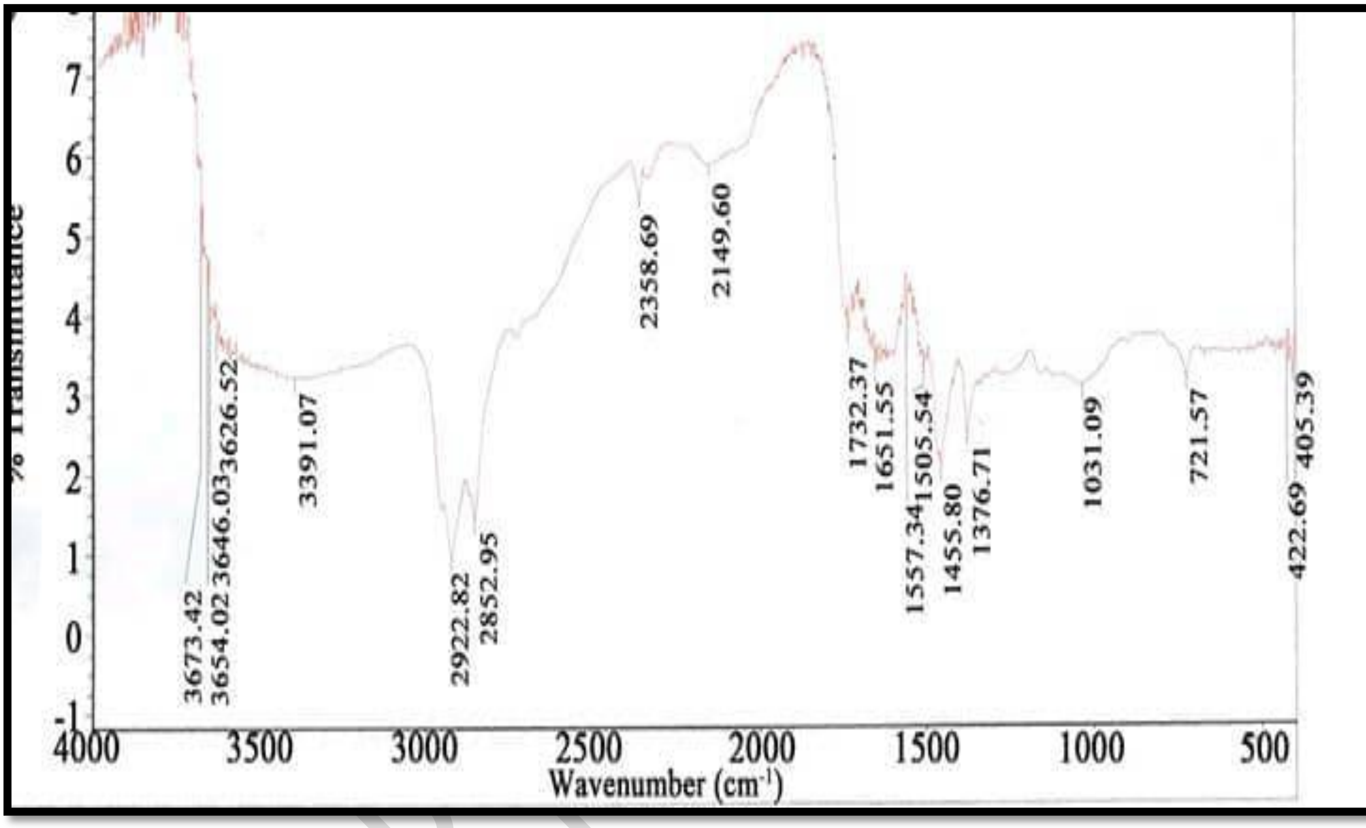


Fig. 3: FTIR spectra of sawdust

3.3 Gas Chromatography Mass Spectroscopy (GC-MS) analysis

The range for methane in a biogas composition should be within 50-70% as reported by Muvhiiwa et al. [8]. And this study methane % for 2.5 kg sawdust and 2.5 kg human faeces was 62.76% which is within an ideal range as analyzed by the GCMS machine.

3.4 Weekly biogas production for 44 days

The yield and different compositions of the generated biogas are shown in Table 4. Digesters 6 (containing 2.50kg of human faeces to 2.5kg of sawdust to 5 liters of water) had the highest cumulative biogas yield of 5.43 L for 44 days, and digester 1 (consisting of 5.0kg of sawdust alone) yielded the lowest cumulative biogas yield of 4.42 L, The pH of 6.45 showed a positive correlation with the daily biogas yield and with the slurry temperature as depicted in runs 6, Table 4.

Table 4: Temperature, pH and Biogas yield in the Digesters

	INPUTS		RESPONSE		
Run	A:Human Faeces Kg	B:Sawdust Kg	Temperature C	pH	Biogas Yield L
1	0	5	27	4.38	4.42
2	2.5	2.5	33.5	6.43	5.37
3	5	0	30.5	5.5	4.89
4	1.25	3.75	31.5	5.7	5.11
5	5	0	31	5.34	4.93
6	2.5	2.5	34	6.45	5.43
7	3.75	1.25	33	6.18	5.32

3.5 Optimization of the predicted and Actual values for the experimental results

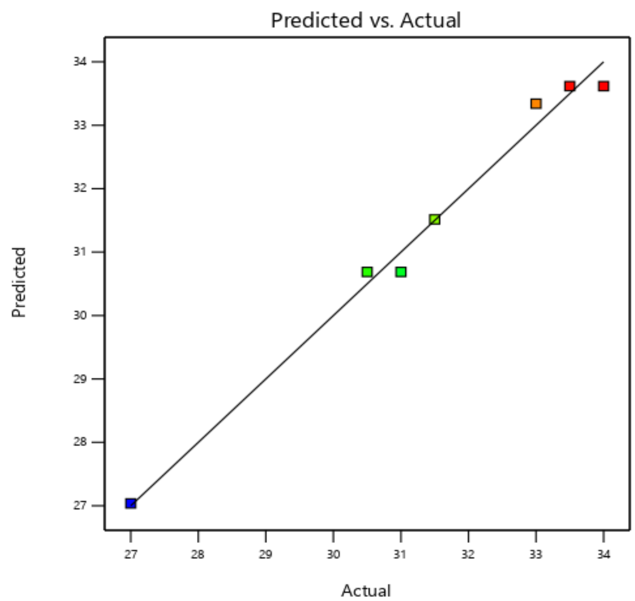
Utilizing the design expert software, optimization was conducted for the experimental design Table 5 The coded equations in Eqn (4) were generated in the Optimal (Custom) Design of Mixture on each case and used to calculate the predicted values of the experiment. Table 5 depicts that the three response considered are in good alignment but the model is well suited with biogas yield (this study). When compared to [1] although, with different biomaterials and Design Expert subset, it outperformed the already existing findings as shown in Table 5 as corroborated by the R^2 values.

Table 5:Model fitness parameters and their Comparison

Parameters	Temperature	pH	This study	Biogas Yield [1]
Model p-value	0.0001	< 0.0001	< 0.0001	< 0.0001
Lack of Fit p-value	0.6082	0.4295	0.8335	0.7402
Standard Deviation	0.3206	0.0870	0.0279	0.0040
Mean	31.50	5.71	5.07	0.3724
C.V. %	1.02	1.52	0.5511	1.07
R^2	0.9879	0.9906	0.9959	0.9855

Adjusted R^2	0.9819	0.9860	0.9938	0.9751
Predicted R^2	0.9671	0.9738	0.9854	0.9566
Adeq Precision	31.3534	35.3788	53.1723	28.9586

Reference [1] is co-digestion of maize chaff and cow rumen



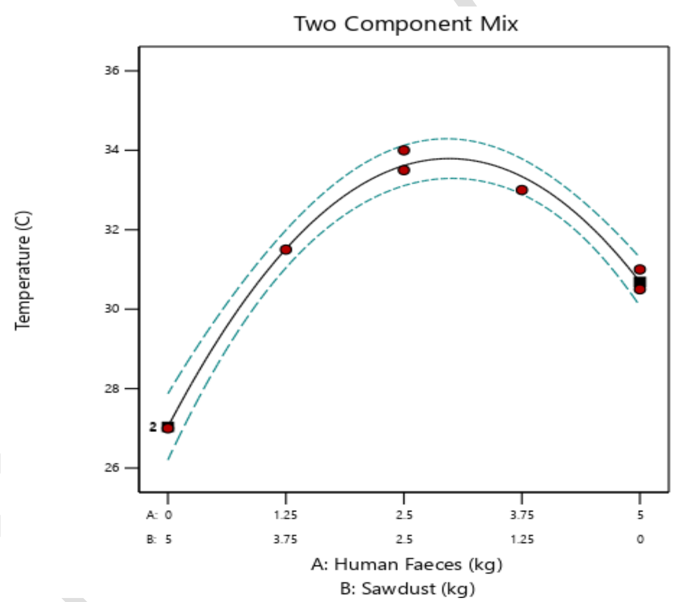
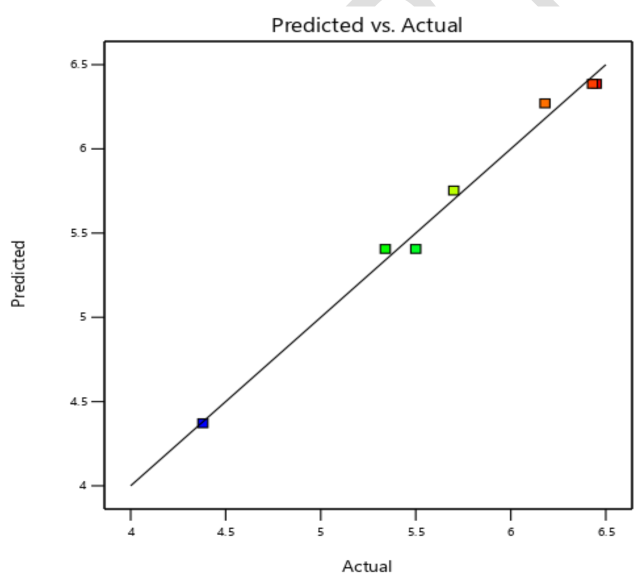


Fig. 4a: Predicted vs. Actual plot for Temp.**Fig. 4b:** Effect of Two Mixing Parameters for Temp.



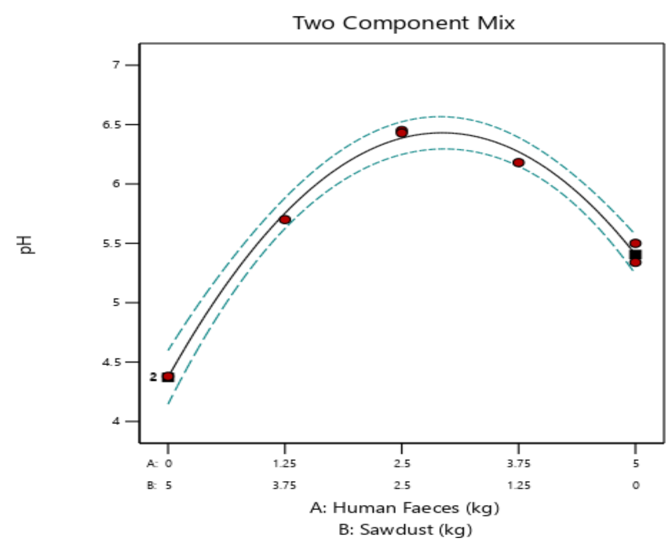
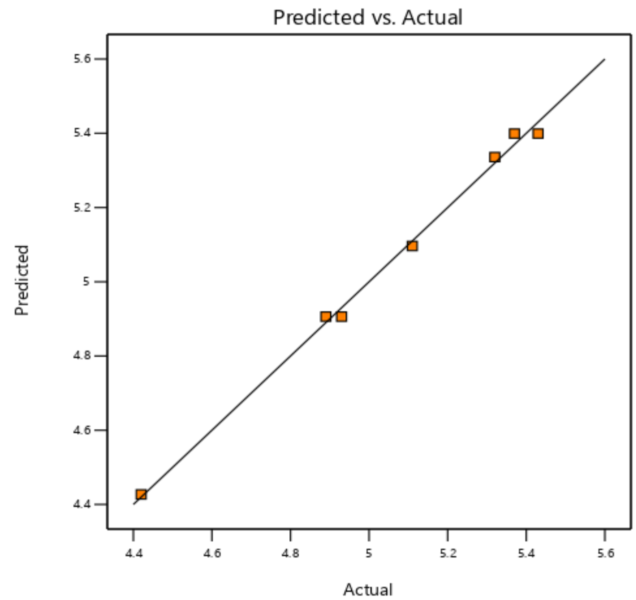


Fig. 5a: Predicted vs. Actual plot for pH **Fig. 5b:** Effect of Two Mixing Parameters for pH



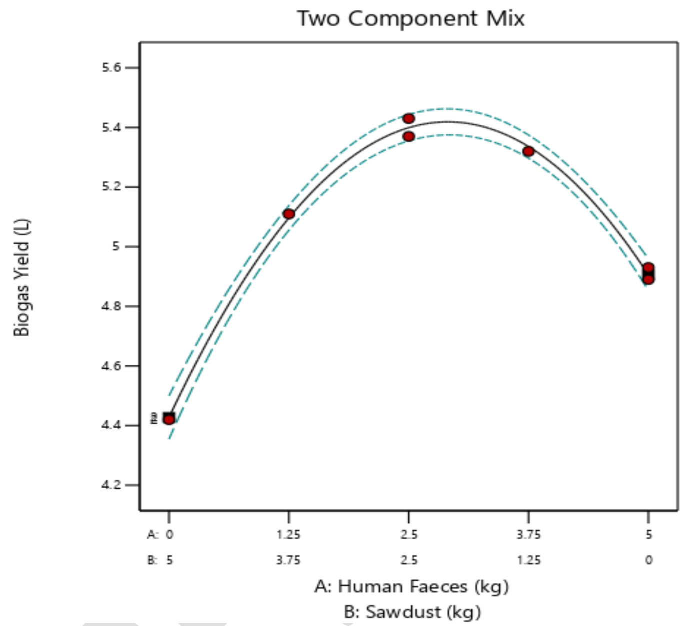


Fig. 6a: Predicted vs. Actual plot for biogas.**Fig. 6b:** Two Mixing Parameters Effect for Biogas

Biogas Yield = + 4.91 A + 4.43 B + 2.93 AB　　　　Eqn (4)

Equation (4) uses coded parameters to explain the actual quadratic regression equation that describes the statistical link between the model yield and the two independent elements.

Figs. 4a, 4b, 5a, 5b, 6a, 6b shows the graphical representation of the predicted and actual values, and the plots for the effect of two mixing parameters of the experiment for the measurement of the temperature, pH values and biogas yield during the experiment. Also, 5a, 6a and 7aplots confirms 95% similarities between the predicted and actual values. And these plotshelps in understanding the validity of the data modeled and the chosen model. The data points are quite close or aligned to the fitness of the line, demonstrating a good approximation of the model. This further supports the model's strong coefficient of correlation. Additionally, the two mixing parameter plot as shown in Fig. 4b, 5b, 6b shows the core influencing elements for a better performance. And this can be translated into an industrial scale for industrial development and to alleviate poverty and hardship as a result of worsening economic crisisof countries like Nigeria presently. Thus, 2.5kg sawdust co-digested with 2.5 kg treated human faeces gave the best output as influenced by their corresponding pH and temperature as corroborated by Table 4.

3.6. Future Scope

Future work on biogas should be to translate this experimental approachto an industrial scale for effective utilization especially for those in rural vincinity, since the biomaterials are readily available, thereby, reducing drastically cost of energy and dangerous emissions from the usage of fossil fuel.

4. Conclusion

This work has shown that the co-fermentation of sawdust and treated human manure could significantly enhance biogas yield. Bioconversion of biomaterials like the co-digestion sawdust and treated human faeces to produce biogas isa viable, economical and eco-friendly approach to the management of the enormous quantities of wastes generated from agricultural activities while harnessing the opportunity to produce carbon-neutral biogas on a larger scale to replace fossil fuels. From the outcome, the logistic function model performance was satisfactory in the simulation of the experimental process. The codigestion of sawdust and human faeces at 2.5 kg each produced the highest biogas output of 5.43 L using Optimal (Custom) Design of Mixture approach. The high coefficient of determination (R^2) ranging between 0.9959 - 0.9879 and standard deviation of 0.023 - 0.321 for temperature - biogas yield respectively, fall within an ideal range. Thus, the model proved to be a useful tool in predicting anaerobic digestion and biogas production processes. Furthermore, the FTIR analysis of sawdust and human faeces indicates their potential to produce biogas if subjected to anaerobic environment. In addition, the GCMS analyzed the % of methane to be 62.76% which is within accepted range. Thus, this experiment can be translated to an industrial scale biogas production for cooking and electricity to boost local economy and alleviate poverty.

Declarations

Manuscript Processing Time

Normal timeframe

Data Availability

Consider data availability to be made available on request.

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